

A Comparison of Spin Observable Predictions for RHIC

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Abstract

There have been many versions of spin-dependent parton distributions in the literature. Although most agree with present data within uncertainties, they are based upon different physical assumptions. Some physical models are discussed and the corresponding predictions for double spin asymmetries are shown. A summary of the most feasible measurements in the appropriate kinematic regions at RHIC, which should yield the most useful information about the polarized gluon distribution, is given.

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1 Introduction

Recent polarized deep-inelastic experiments have yielded valuable information about the quark helicity distributions in the proton, but have left some crucial questions unanswered. One of the key unknowns is the size of the polarized gluon distribution. In light of the data, there have been numerous constituent models reflecting contributions of quarks and gluons to the proton spin.[1, 2, 3, 4] Most of these models reproduce existing data fairly well, but vary as to their physical assumptions and the overall functional form. There is a wide variety of results for the polarized strange sea and the polarized gluons in the proton, for example. Since the constituent distributions are used for predicting the spin observables, their measurement can be used to distinguish between the physical assumptions of these models. Hence, further experimental information is necessary in order to understand the nature of these constituents, in particular, the polarized glue.

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven (BNL) is well suited for the polarized beam experiments which can help to reveal the nature of the proton constituents' spin properties. The two major detectors, STAR and PHENIX, cover a similar kinematic region, but STAR has wider angular coverage, while PHENIX has finer granularity for more precise measurements.

This paper discusses the optimal observables for these detectors to determine ΔG . Section II will provide a brief overview of some theoretical models of the spin constituents of the proton. The physical assumptions and use of present polarized DIS data will be discussed. In section III, key experimental predictions for the determination of ΔG will be compared. Finally, suggestions are made for the best possibilities to experimentally determine the nature of ΔG in the accessible kinematic regions of the two detectors.

2 Models of the Polarized Distributions

In recent work[1, 5] we constructed three sets of polarized parton distributions for the valence and sea quarks, based upon three models for the polarized gluons. Each gluon model has a different physical basis, but the quark distributions conform to a set of reasonable theoretical assumptions. All of the distributions are generated at $Q_0^2 = 1.0 \text{ GeV}^2$ and evolved in NLO, entirely in x -space, up to the Q^2 values necessary to predict the spin observables. All three sets are in good agreement with data.

The polarized valence distributions are generated from a modified SU(6) distribution with a spin dilution factor to control their small- x behavior. The polarized valence distributions are written in terms of the unpolarized CTEQ distributions as:

$$\begin{aligned}\Delta u_v &= \cos \theta_D [u_v - \frac{2}{3}d_v] \\ \Delta d_v &= \cos \theta_D [-\frac{1}{3}d_v],\end{aligned}\tag{1}$$

where the spin dilution factor is: $\cos \theta_D = [1 + R_0(1-x)^2/\sqrt{(x)}]^{-1}$. The free parameter, R_0 , is fixed by applying the Bjorken Sum Rule. In the Q^2 region of the present PDIS data, we find that $R_0 \approx \frac{2}{3}\alpha_s$. This parametrization gives the appropriate behavior at both small and large x .

Table 1: Parametrizations for Polarized Sea Flavors

Flavor	ΔG	A	B	P(x)
$\Delta \bar{u}$	xG	0.317	1.124	$-\delta(x) - 1.682x^{0.937}(1-x)^{-3.368}(1 + 4.269x^{1.508})$
Δd	xG	0.317	1.124	$+\delta(x) - 1.682x^{0.937}(1-x)^{-3.368}(1 + 4.269x^{1.508})$
Δs	xG	0.107	1.257	$-3.351x^{0.937}(1-x)^{-3.368}(1 + 4.269x^{1.508})$
$\Delta \bar{u}$	0	0.386	0.990	$-\delta(x)$
Δd	0	0.386	0.990	$+\delta(x)$
Δs	0	0.173	1.070	0
$\Delta \bar{u}$	< 0	0.414	0.954	$-\delta(x) - 10.49x^{1.143}(1-x)^{-1.041}(1 + 0.474 \ln x)$
Δd	< 0	0.414	0.954	$+\delta(x) - 10.49x^{1.143}(1-x)^{-1.041}(1 + 0.474 \ln x)$
Δs	< 0	0.212	0.997	$-20.89x^{1.143}(1-x)^{-1.041}(1 + 0.474 \ln x)$

For the polarized sea, we assume a broken SU(3) model, to account for mass effects in polarizing the strange sea. Our models separate all light flavors in the valence and sea. Charm is included via the evolution equations (N_f), at the appropriate Q^2 of charm production, to avoid any non-empirical assumptions about its size. The small- x behavior is of the Regge type, and the large- x behavior is compatible with the appropriate counting rules.[3]

The polarized sea distributions are extracted from both the unpolarized CTEQ sea distributions and polarized deep-inelastic-scattering data.[5] We assume a model of the sea which obtains its polarization from gluon Bremsstrahlung, so the net polarization of the quarks is dependent upon their density in hadrons in LO. We therefore assume that these densities are directly proportional and the flavor dependent sea distributions have the form

$$\Delta q_i = \eta_i(x) \cdot x \cdot q_i(x). \quad (2)$$

The η_i are determined from the integrated distributions and sum rules used to analyze polarized deep-inelastic-scattering data. We have chosen the functional form of $\eta_i(x)$ to have a reasonable Regge type behavior, to be consistent with positivity constraints and to yield the proper normalization (indicated here by the factor η) in reflecting the relative spin that each flavor contributes to that of the proton. Here, $\eta_i(x)$ may be interpreted as a modification of $\Delta q(x)$ due to unknown soft effects at small- x . The normalization requires that $\int_0^1 \Delta q_i(x) \cdot dx = \int_0^1 \eta_i(x) \cdot x q_i(x) \cdot dx = \eta \cdot \int_0^1 x q_i(x) \cdot dx$. The overall parametrization for each of the polarized sea flavors, including the $\eta(x)$ functions, the anomaly terms and the up-down unpolarized asymmetry term can be written (with the CTEQ basis) in the form:

$$\Delta q_i(x) = -Ax^{-0.143}(1-x)^{8.041}(1 - B\sqrt{x})[1 + 6.112x + P(x)]. \quad (3)$$

The values for the variables in this equation are given for each flavor and each gluon model in Table I. Note that $\delta(x) \equiv 0.278x^{0.644}$ is due to the asymmetry of the unpolarized up and down anti-quarks.

We consider three distinct models for the polarized gluons, which have a moderate size. There exists no empirical evidence that the polarized gluon distribution is large at the relatively small Q^2 values of the data. Data from the Fermilab E704 experiment indicate that it is likely small at these Q^2 values. In addition, a theoretical model of ΔG based on counting rules, implies that $\Delta G \approx \frac{1}{2}$. [3] Our choice of models effectively includes two

separate factorization schemes, Gauge Invariant (GI or \overline{MS}) and Chiral Invariant (CI or Adler-Bardeen), which can be used to represent the polarized sea distributions.[7]

The first set of $\Delta q_i(x)$ functions, quoted in Table I assumes a moderately polarized glue, normalized to $\frac{1}{2}$ using the CTEQ unpolarized gluons. The second polarized gluon model assumes $\Delta G = 0$. This is equivalent to writing the quark distributions in the gauge-invariant scheme, since the anomaly term vanishes. The third model is motivated by an instanton-induced polarized gluon distribution, which gives a negatively polarized glue at small- x . [8] The three polarized gluon distributions are written as

$$\begin{aligned}\Delta G(x) &= xG(x) \\ \Delta G(x) &= 0 \\ \Delta G(x) &= 7(1-x)^7[1 + 0.474 \ln(x)].\end{aligned}\tag{4}$$

Our overall distributions agree very well with existing data.

The models of Gehrmann and Stirling are based upon an SU(3) symmetric sea with the small- x behavior of the sea and glue assumed equal. All of the difference between the Ellis-Jaffe sum rule and the data are attributed to ΔG , with $\Delta s \rightarrow 0$. This differs considerably with our models. They also have three different polarized gluon models, which run the range of hard and soft gluons. The GSA ΔG is much larger than that of our first model. The other two fall within the range of ours, and are therefore not discussed here. Our motive is to present a wide range of models for ΔG so that the experiments can be used to distinguish the size of ΔG as opposed to the overall accuracy of a particular model. The differences in the predictions of the GSA and the three GGR models (A, B, and C)[1] are thus due to the x -behavior of the quark distributions and the relative sizes of ΔG .

3 A Comparison of Experimental Predictions

The polarization experiments planned for RHIC show great potential for extracting information on polarized distributions, especially ΔG . With polarized beams of 70% polarization and luminosity of $2 \times 10^{32} / \text{cm}^{-2} / \text{sec}^{-1}$, both prompt- γ production and jet production can be done in a kinematic region where determination of ΔG is possible. If the planned integrated luminosity of 320 pb^{-1} at $\sqrt{s} = 200 \text{ GeV}$ is attained, the resulting data should be good enough to distinguish among many of the polarized gluon models which have been proposed.

The STAR detector will have a wide angular range to cover a large rapidity, especially for jet production. The PHENIX detector has a narrow rapidity, but finer granularity, and is well suited for measuring high p_T prompt photons. Both are planned to have an accessible p_T range of $10 \leq p_T \leq 30 \text{ GeV}$ at $\sqrt{s} = 200 \text{ GeV}$. The predictions shown here cover this kinematic range. Possible experiments which would provide a measure of ΔG include:

- one and two jet production in $e - p$ and $p - p$ collisions, [2, 9]
- prompt photon production[2, 9]
- charm production[10]
- polarized heavy quark production[11]: these asymmetries are between one and four percent for $\sqrt{s} = 200 \text{ GeV}$ with $p_T \geq 5 \text{ GeV}$

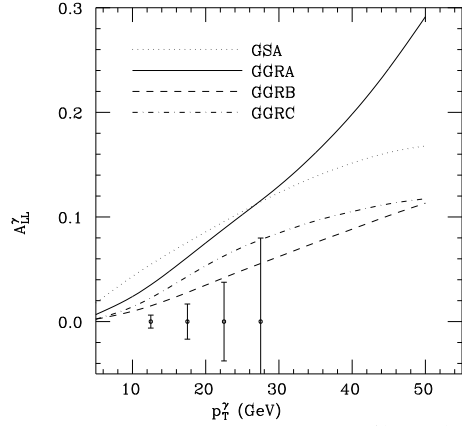


Fig. 1: Prompt- γ asymmetry at $\sqrt{s}=200$ GeV.

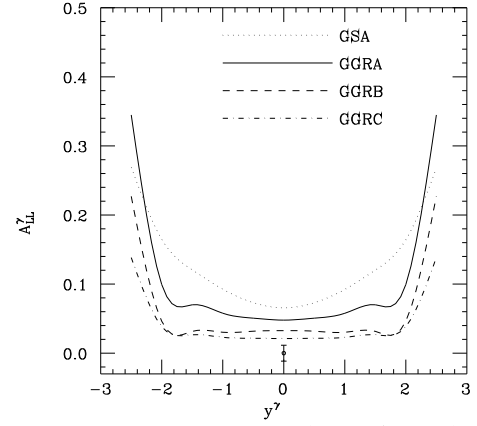


Fig 2: Asymmetry at $p_T=15$ GeV for $\sqrt{s}=200$ GeV.

- χ_{0c} and χ_{1c} production[12]: for very large models of ΔG , these asymmetries range from eight down to one percent for $\sqrt{s} = 500$ GeV and $2 \leq p_T \leq 30$ GeV.
- χ_{2c} production[2]: even for the larger models of ΔG , these asymmetries range from zero to four percent at $\sqrt{s} = 200$ GeV and $2 \leq p_T \leq 8$ GeV.
- J/ψ production [13] these asymmetries are typically from two to six percent at $\sqrt{s} = 200$ GeV and $2 \leq p_T \leq 10$ GeV.
- pion production [14].

All but the first two of these yield small asymmetries, even for moderately sizable gluon polarizations. Thus, we feel that jet production and prompt- γ production are the best choices for extracting information about ΔG . The asymmetries are not large everywhere, but there are kinematic regions where models based upon the different sizes of ΔG can be distinguished. We have calculated prompt- γ production in LO and NLO, and jet production at LO. The figures compare the predictions of our three models with the Gehrman and Stirling A model.

Figure 1 compares the predictions of the GSA (large ΔG) with the three GGR gluon models for the prompt photon asymmetry, A_{LL}^{γ} . The error bars shown are those expected for A_{LL}^{γ} at the PHENIX detector in these kinematic regions. Figure 2 shows the same asymmetry predictions at fixed p_T of 15 GeV as a function of rapidity. The error bar shown is for PHENIX, which operates at essentially this point of rapidity. STAR has a much wider rapidity coverage, $-1 \leq y \leq 2$. Figure 3 shows the comparison of the four models for jet production at $\sqrt{s} = 200$ GeV for zero rapidity. The asymmetries for jet production at $\sqrt{s} = 500$ GeV are much smaller than for the lower energy.

4 Extracting ΔG

The various polarized gluon models have different physical bases and provide a reasonable range of possibilities, which can be narrowed down by future experiments at RHIC. If the polarized gluon distribution is moderately positive at $Q^2 = 1$ GeV², the asymmetry for

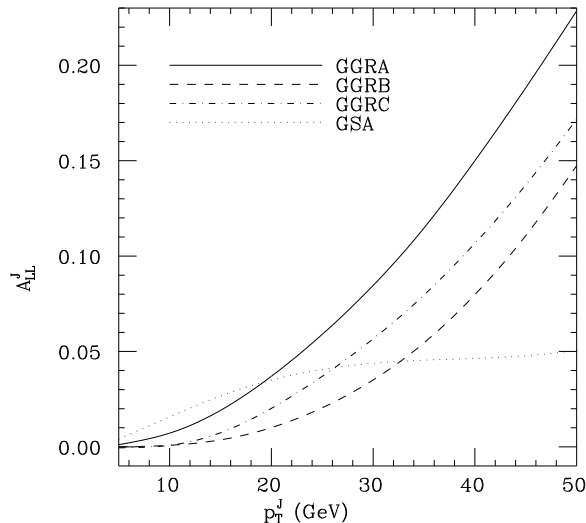


Fig. 3: Jet asymmetry at $y^J=0$ and $\sqrt{s}=200$ GeV.

prompt photon production is among the best candidates for determining the size of ΔG . Jet production will be a close contender for distinguishing among the various predictions for ΔG . Much depends upon the relative errors in the applicable kinematic regions of STAR and PHENIX.

According to the projected uncertainties for STAR and PHENIX, the most favorable region to study prompt photon production is for $15 \leq p_T \leq 25$ GeV at $\sqrt{s} = 200$ GeV. Although the asymmetries are closer together here, the favorable small uncertainties should be able to separate the large and small models for ΔG (Fig. 1). Also, at $p_T = 15$ GeV, the large rapidity region $1 \leq |y| \leq 2$ is a favorable place for STAR to measure the asymmetry due to the separation of predictions in the models (Fig. 2). Since PHENIX is designed for the small rapidity region, the measurement of A_{LL}^γ with the better uncertainties is also promising, and will provide a good cross check of the results obtained by STAR.

Jet production is also a good candidate for determination of whether ΔG is large or small. Since the asymmetries are fairly close together in the p_T region between 15 and 30 GeV, measurements of this asymmetry require the larger values of p_T to distinguish the relative size of ΔG extracted from these predictions (Fig. 3).

Prompt photon and jet production, measured by STAR and PHENIX in these kinematic regions, appear to be the best candidates for providing an indication of the nature of ΔG .

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